



Projet SOLCYP+



AAP Marine Renewable Energy 2017

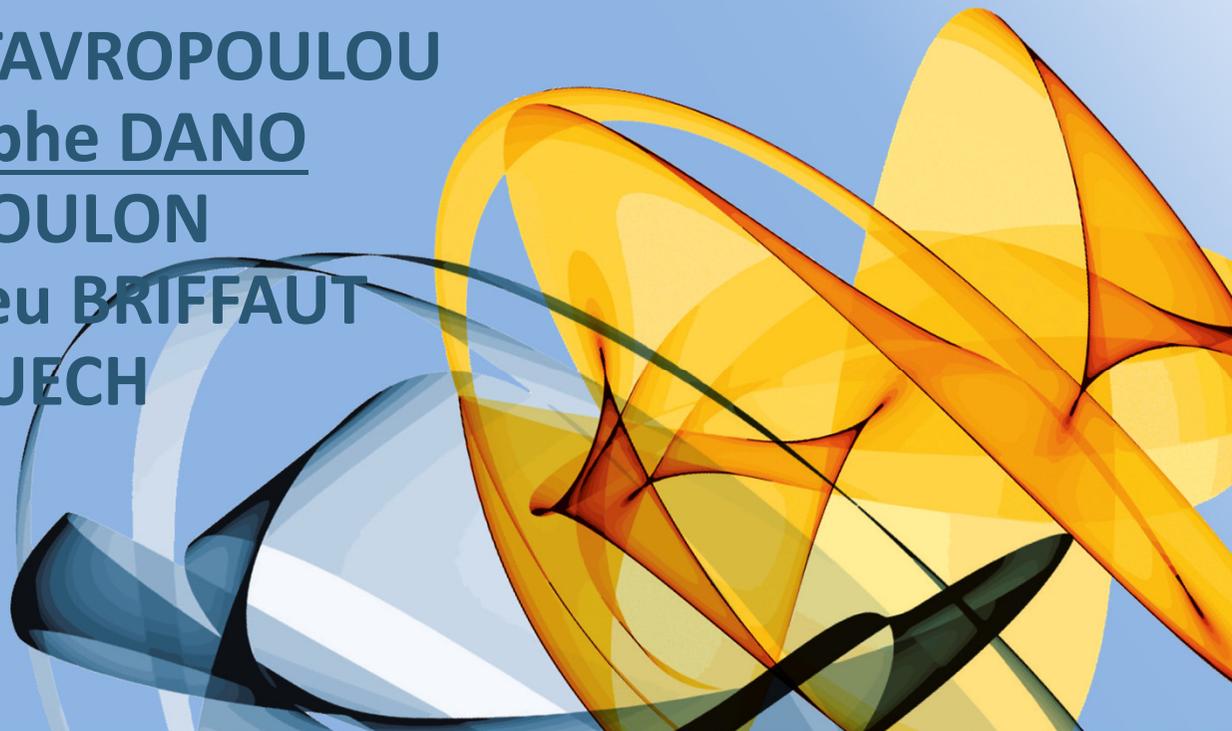
Essais d'interface roche-coulis: premiers résultats



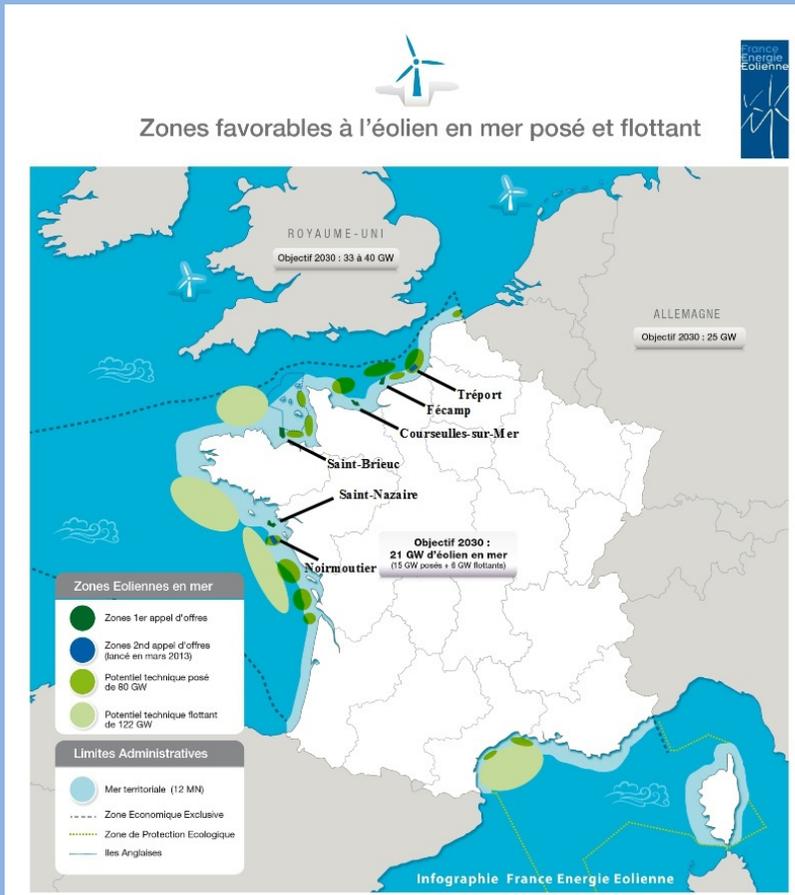
06 Décembre 2018

Fondations des Eoliennes Offshore

Eleni STAVROPOULOU
Christophe DANO
Marc BOULON
Matthieu BRIFFAUT
Alain PUECH



Contexte éolien offshore français

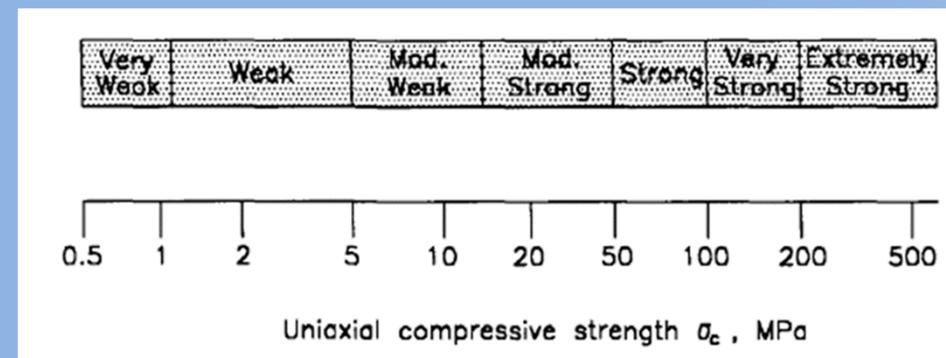


IMPLANTATION DES PARCS EOLIENS

- Roches carbonatées (*calcarénites, calcaire, craie*)
 - Tendres à dures

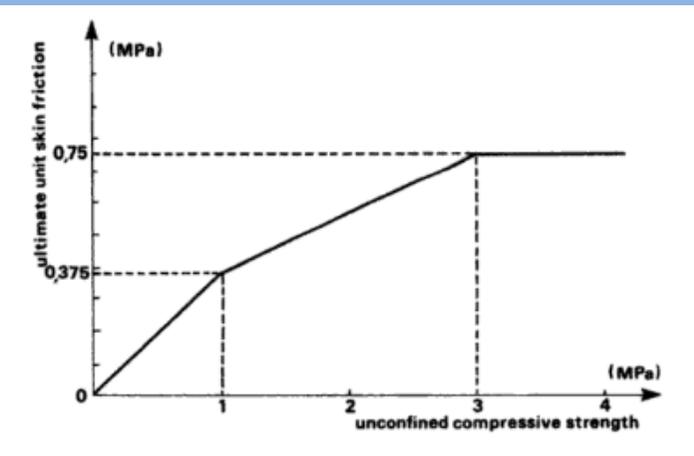
HYPOTHESES :

- pieux forés scellés au coulis
- Interface roche / coulis mécaniquement dimensionnante



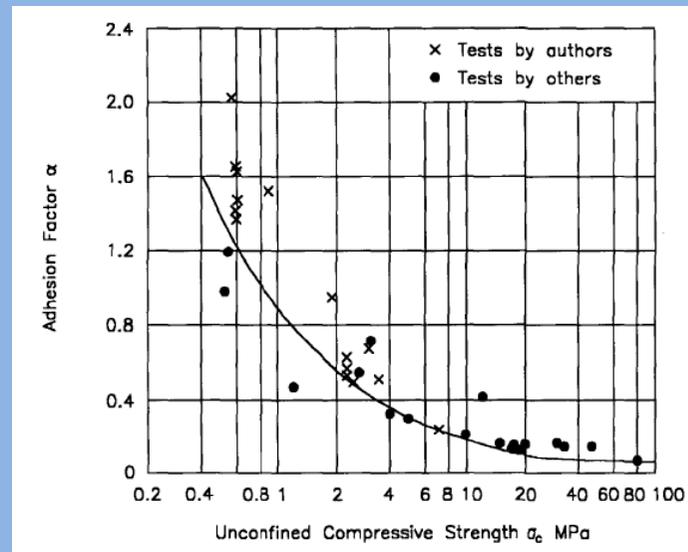
Contexte réglementaire

Frottement latéral roche / coulis : approche (excessivement ?) conservative



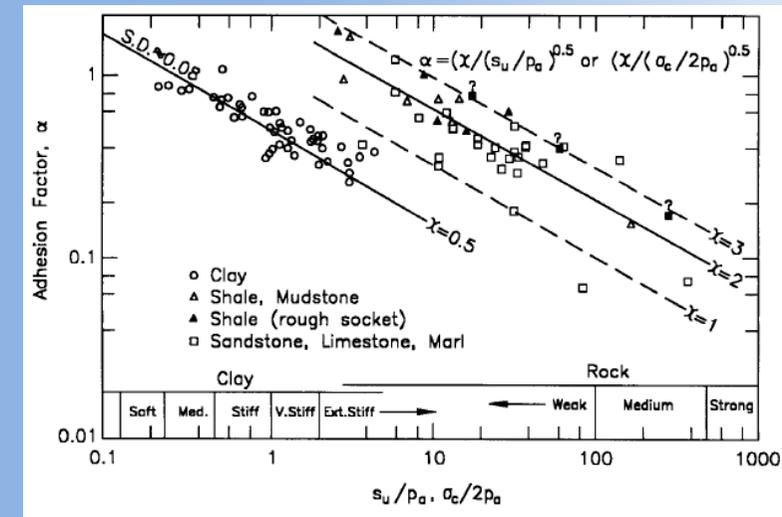
(Abbs & Needham, 1985)
repris par Argema / Clarom

$$F_s \approx 0,1 \text{ à } 0,2 * UCS$$



(Williams et al., 1980)
CIRIA, 1999

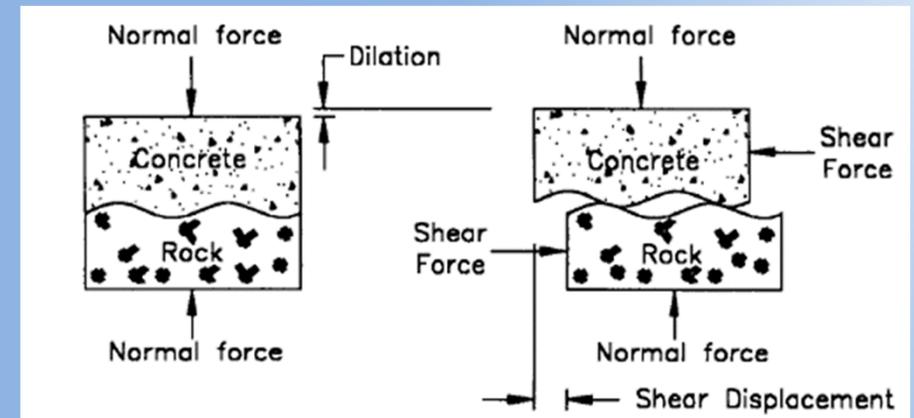
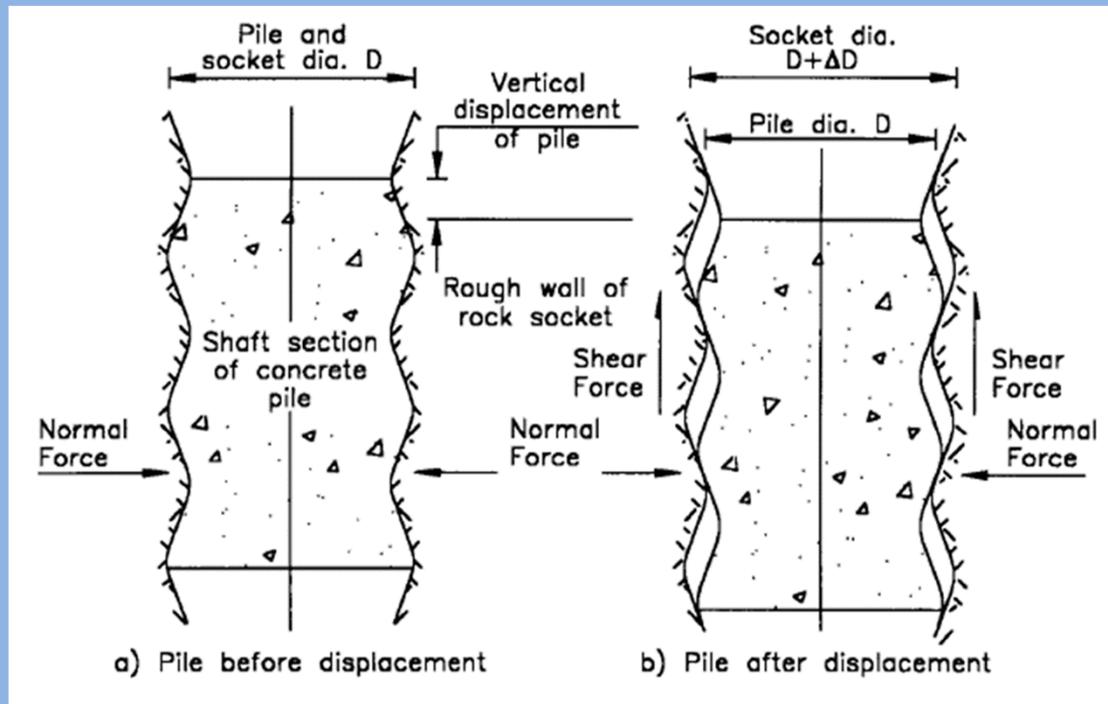
mais rétro-analyse d'essais de pieux laisse
entrevoir des valeurs plus importantes



(Kulhawy and Phoon, 1993)
CIRIA, 1999

Méthodologie

ESSAIS DE CISAILLEMENT D'INTERFACE ROCHE / COULIS



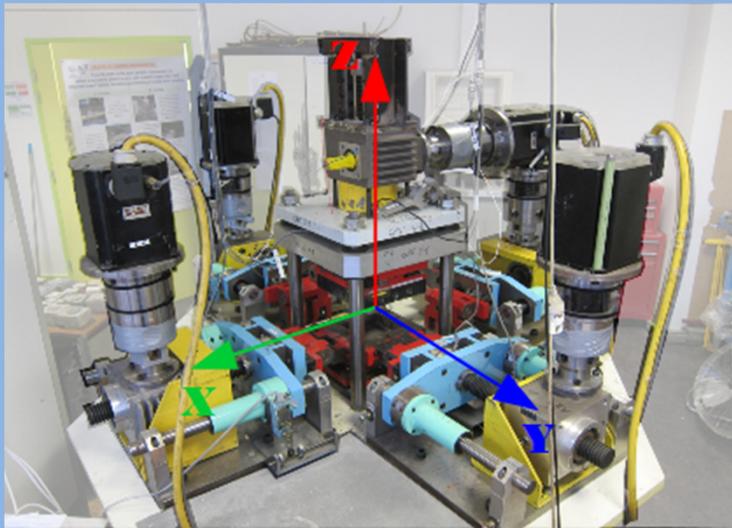
CAMPAGNE D'ESSAIS CNS

$$K = 2 G_m / R_{\text{pieu}}$$

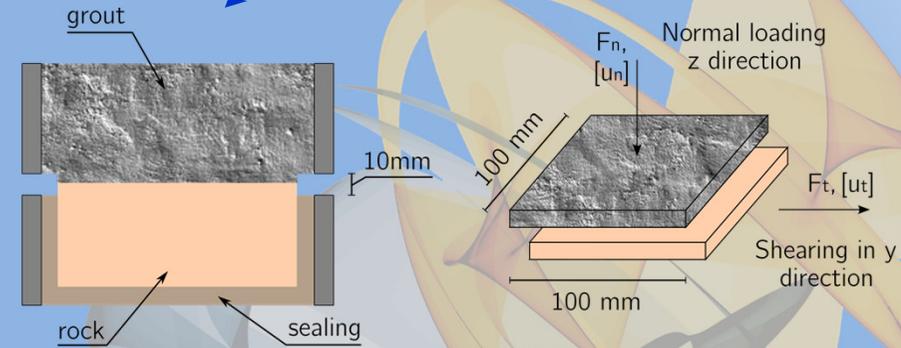
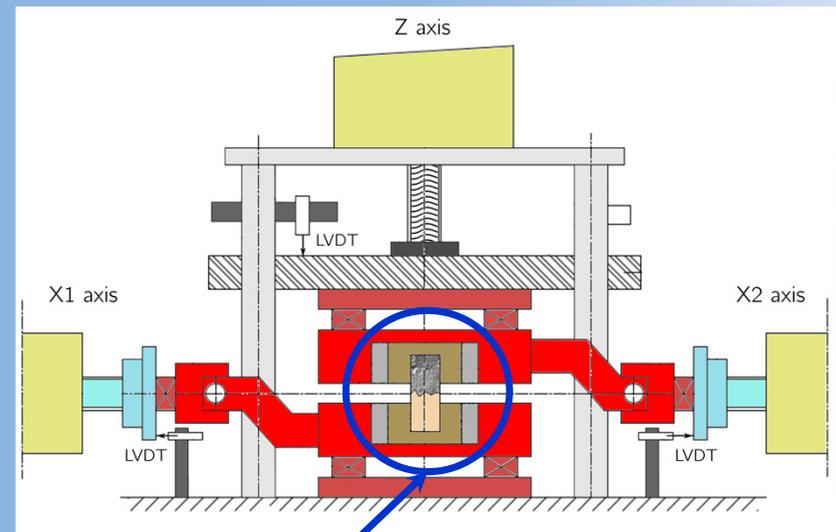
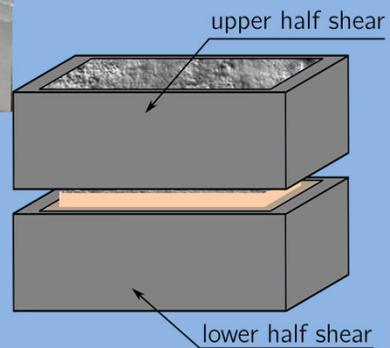
G_m = module de cisaillement
du massif de roche

Méthodologie

ESSAIS DE CISAILLEMENT D'INTERFACE ROCHE / COULIS

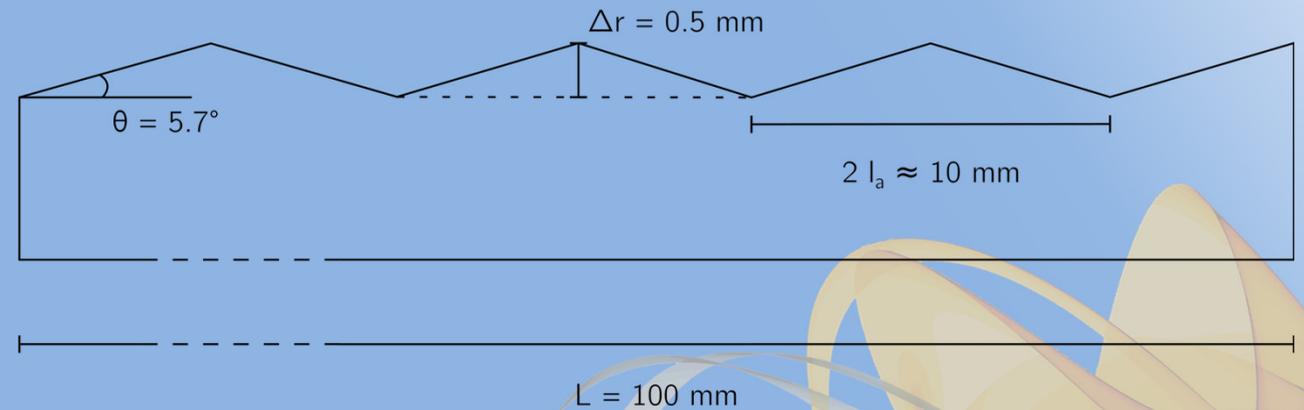
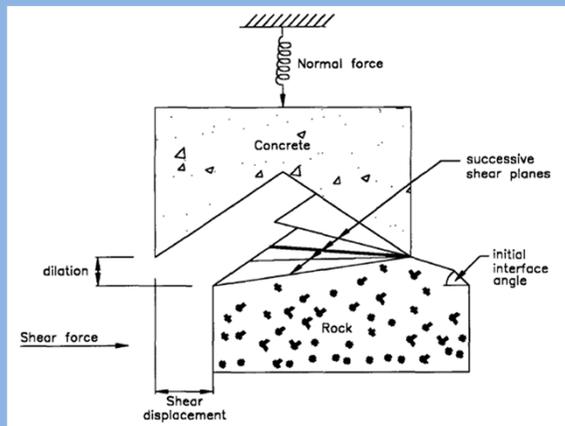


MACHINE BCR3D, Laboratoire 3SR



Méthodologie

COMPORTEMENT MECANIQUE LIE A LA **RUGOSITE (et son évolution)** ET A LA « PROPETE » DU FORAGE



Matériaux

COMPORTEMENT DE L'INTERFACE FONCTION DU CONTRASTE DE RESISTANCE ROCHE / COULIS

SITUATION 1 : **UCS (Roche) < UCS (Coulis)**
(Projet SOLCYP+)

Roche calcaire Franche Fine
de Saint-Maximin (CaCO₃)

$n \approx 25 \text{ à } 35 \%$

UCS (w=0%) = 8.5 MPa, G = 2.2 GPa

UCS (w≈20%) = 6.2 MPa

$R_{TB} = 1.53 \text{ MPa (sec)} / 0.88 \text{ MPa (sat)}$

Coulis de ciment PM 52.5

E/C = 0.4, [C] = 695 kg/m³

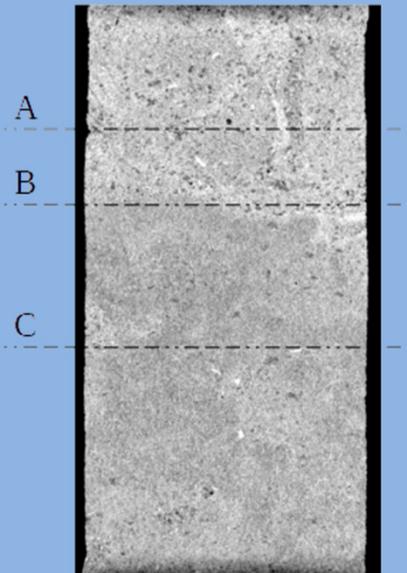
UCS ≈ 42 MPa à 28 jours

SITUATION 2 :
UCS (Roche) > UCS (Coulis)

Calcarénite

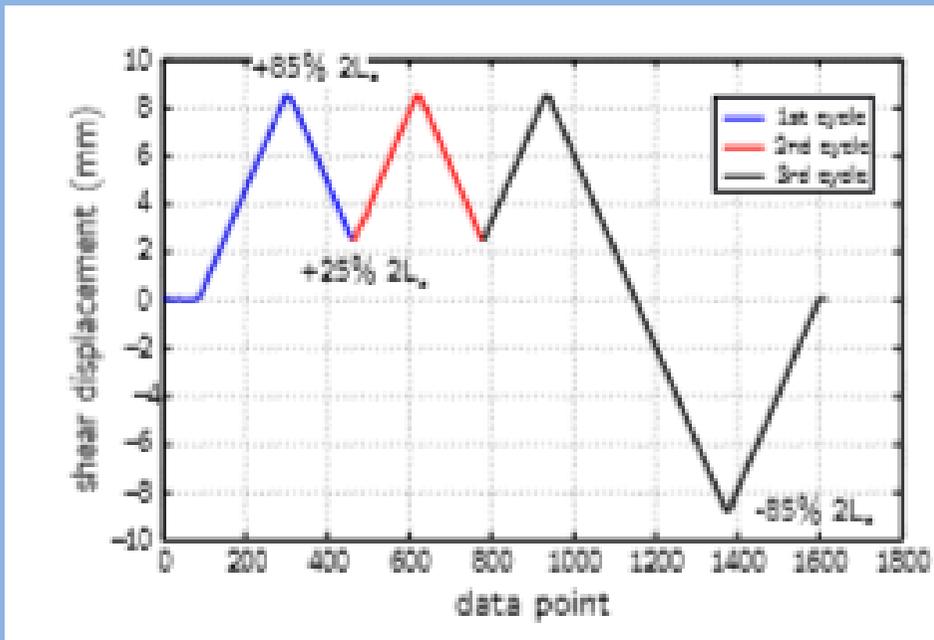
Tata et al. (2014) : CNL, CV

Campagne 2018: CNS



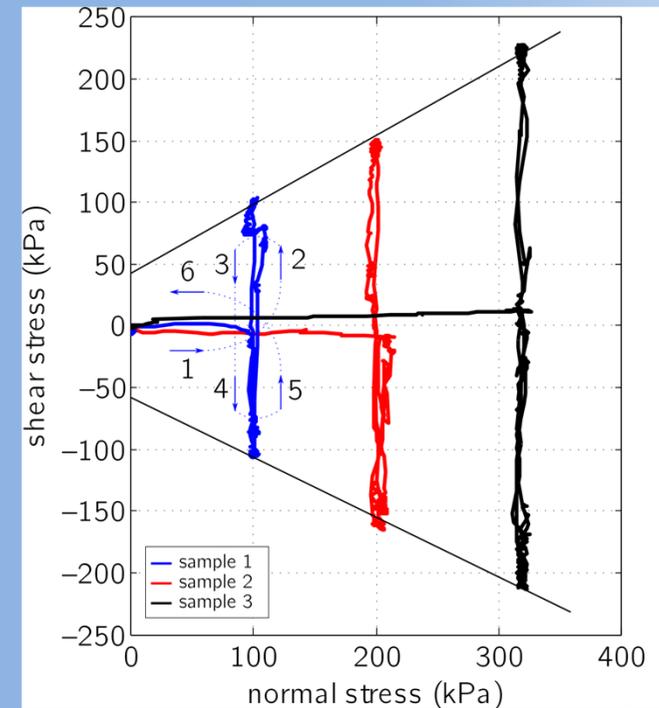
Campagne expérimentale

PHASE 1 : Essais monotones CNL et CNS



Essais CNL roche / roche sans aspérités

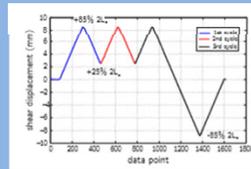
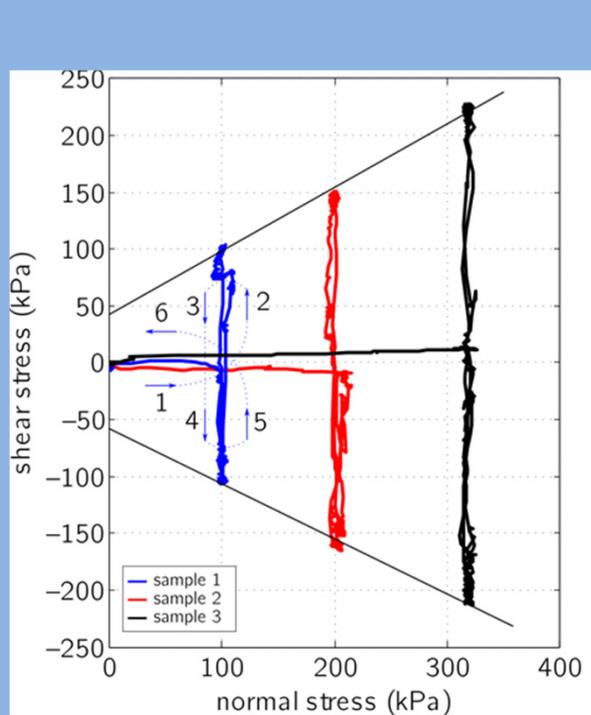
$\sigma_{n0} = 100 / 200 / 300$ kPa



φ^+ (°)	C^+ (kPa)	φ^- (°)	C^- (kPa)
30.0	37.1	26.0	58.8

Campagne expérimentale

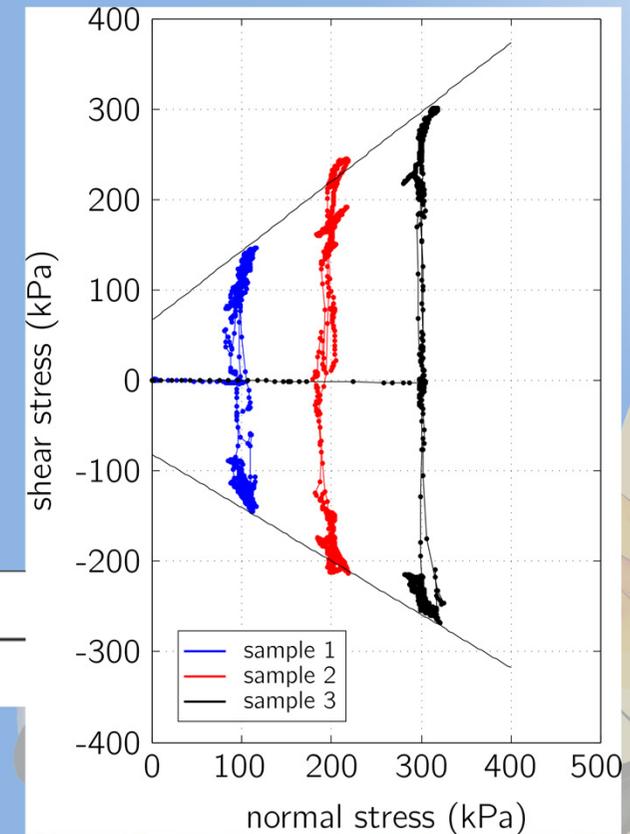
PHASE 1 : Essais monotones CNL et CNS



φ^+ (°)	C^+ (kPa)	φ^- (°)	C^- (kPa)
37.5	66.7	30.5	81.9

Essais CNL roche / roche avec aspérités

$\sigma_{n0} = 100 / 200 / 300$ kPa

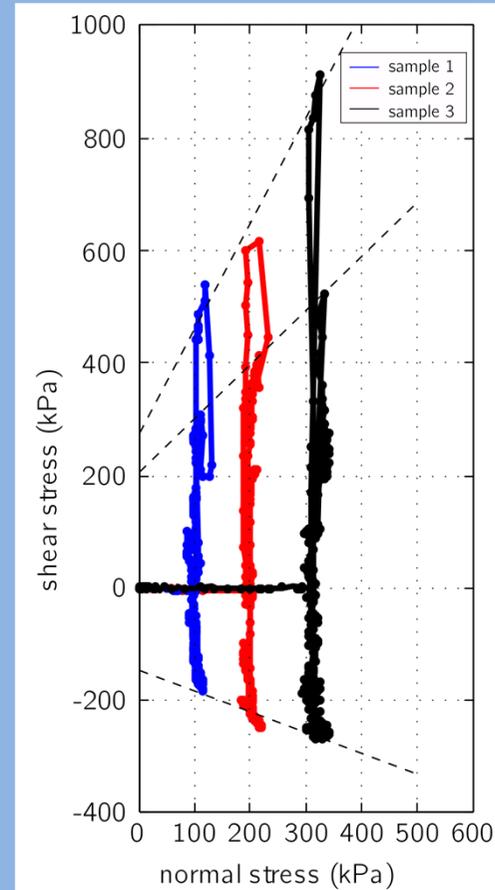
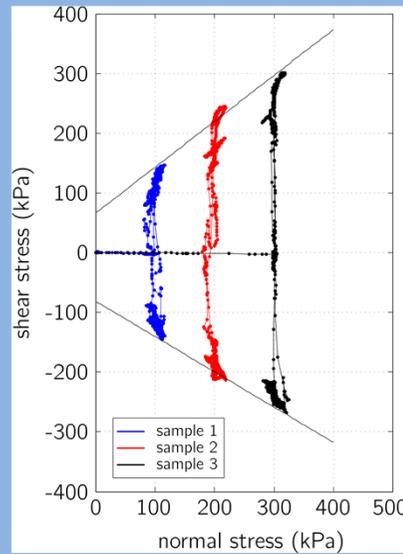
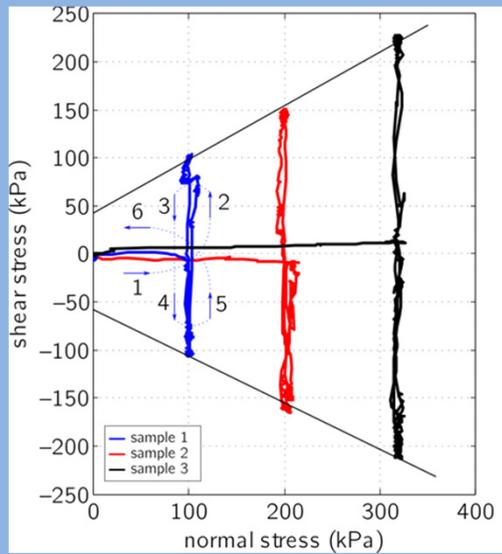


Campagne expérimentale

PHASE 1 : Essais monotones CNL et CNS

Essais CNL roche / coulis avec aspérités

$\sigma_{n0} = 100 / 200 / 300$ kPa



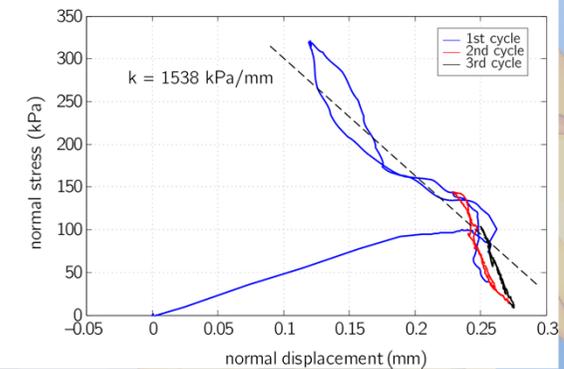
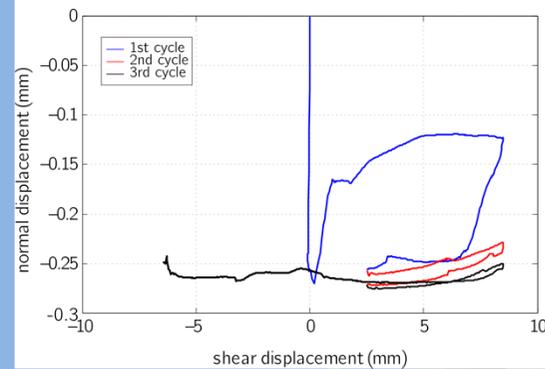
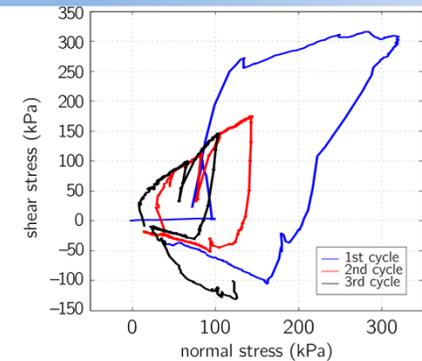
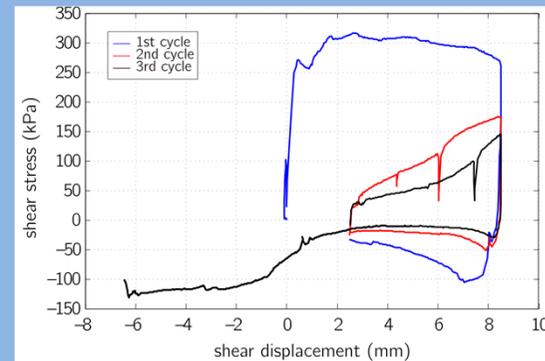
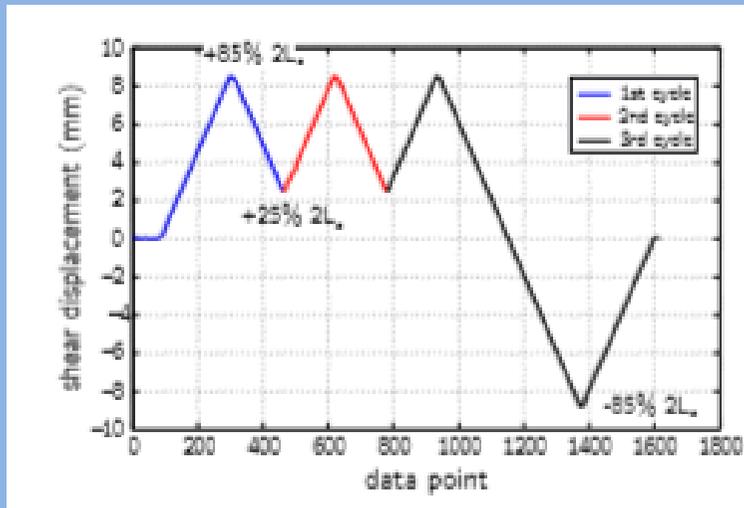
Campagne expérimentale

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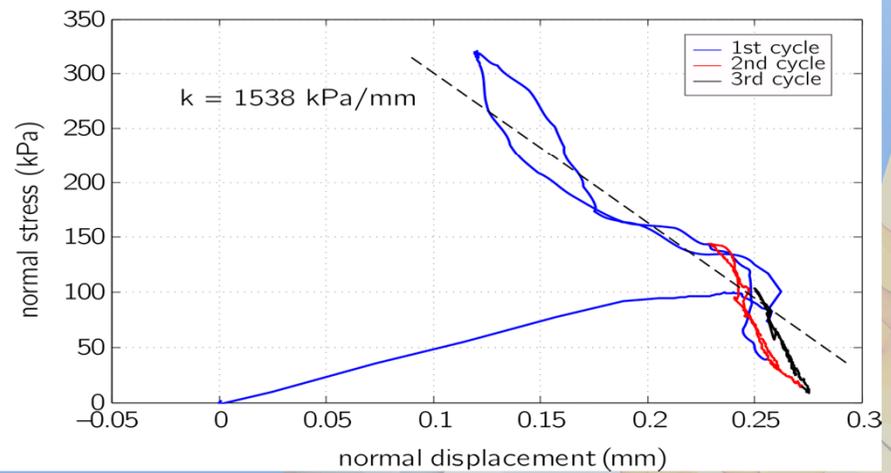
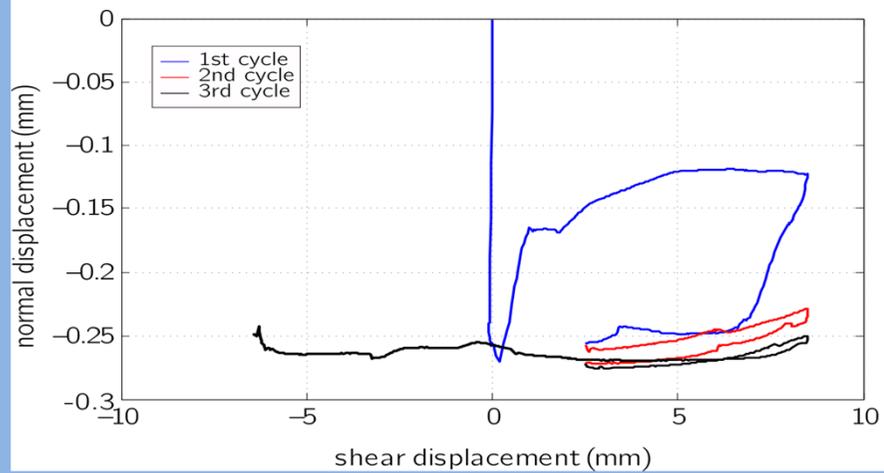
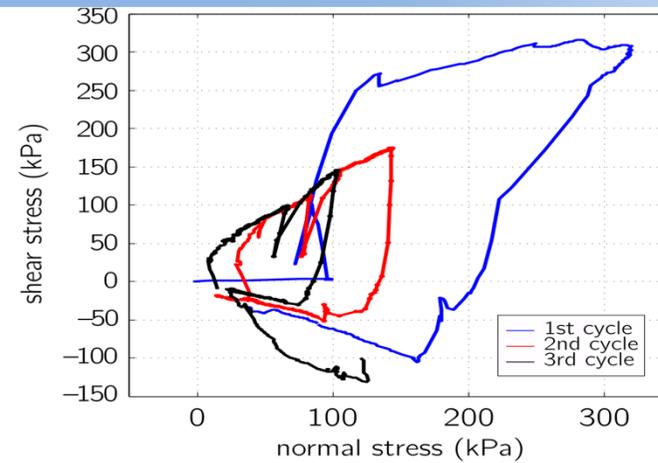
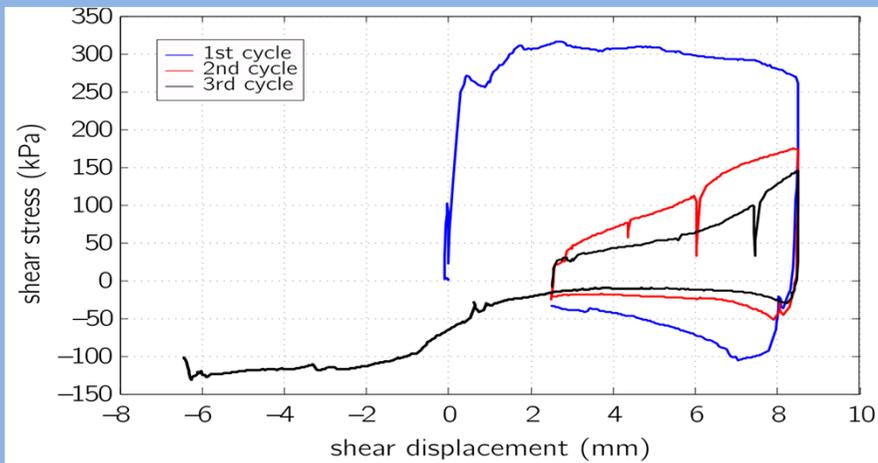
Essais CNS roche / coulis avec aspérités

$$\sigma_{n0} = 100 \text{ kPa}$$

k entre 500 ($R \approx 5\text{m}$) et 2500 kPa/mm ($R \approx 2\text{m}$)

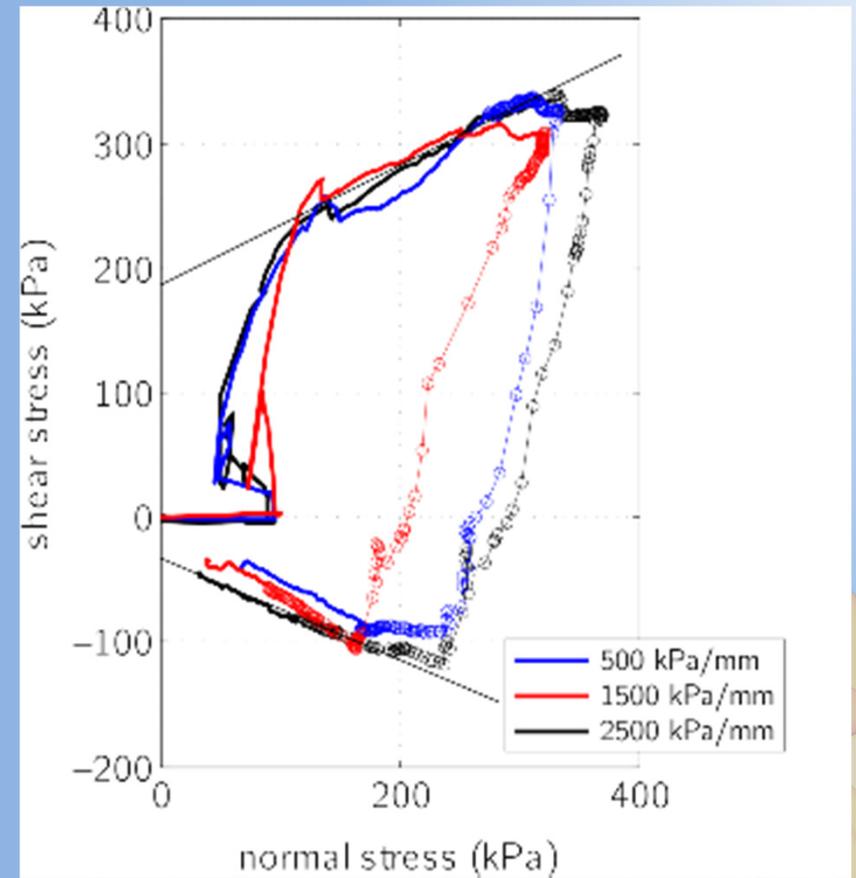
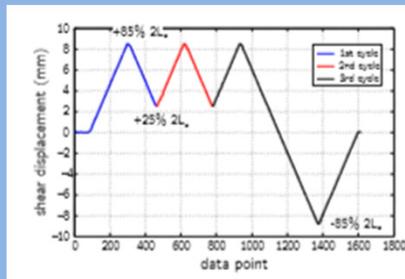


Campagne expérimentale



Campagne expérimentale

PHASE 1 : Essais monotones CNL et CNS



Campagne expérimentale

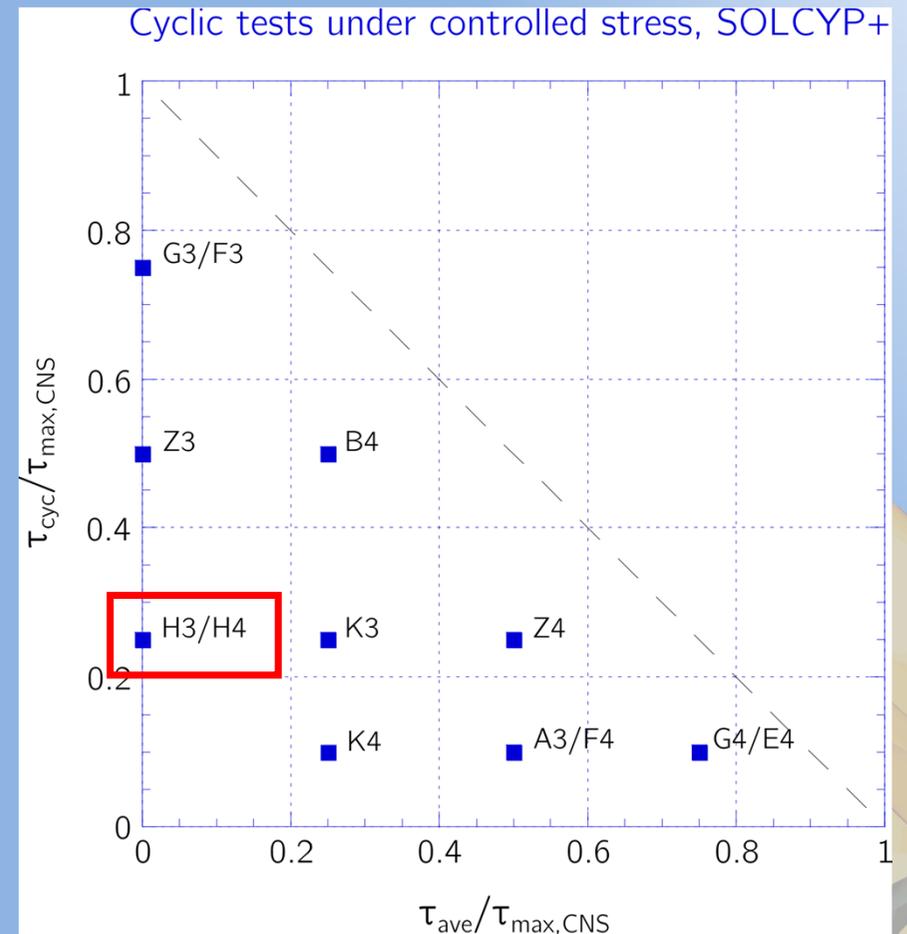
PHASE 2 : Essais cycliques CNS

$$\sigma_{n0} = 100 \text{ kPa}$$

$$k = 1500 \text{ kPa/mm}$$

2 critères d' « arrêt »

- Contrainte normale qui s'annule
- Déplacement tangentiel excessif



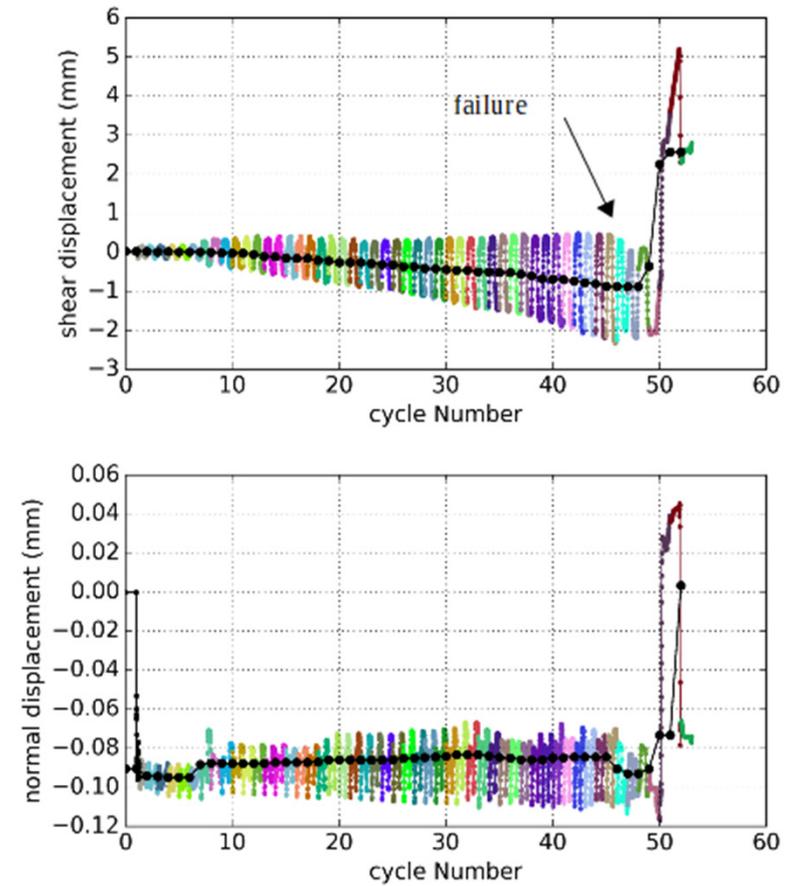
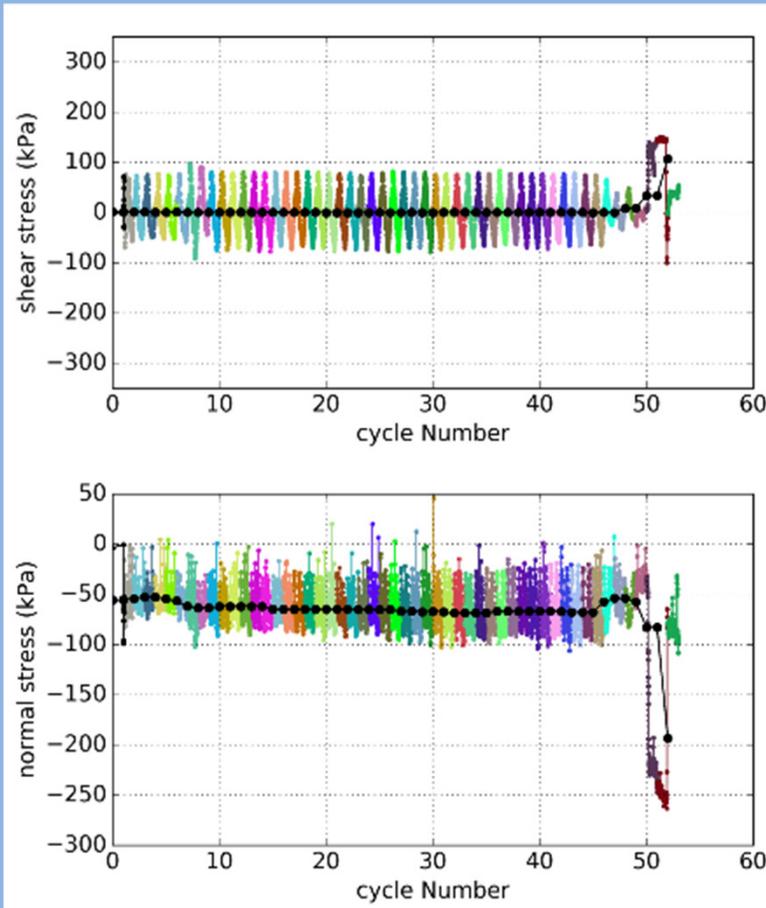
CAMPAGNE EXPERIMENTALE

PHASE 2 : Essais cycliques CNS

Essai H3

$$\tau_{ave} = 0 \text{ kPa}$$

$$\tau_{cyc} = 77.5 \text{ kPa} \\ (25\%)$$



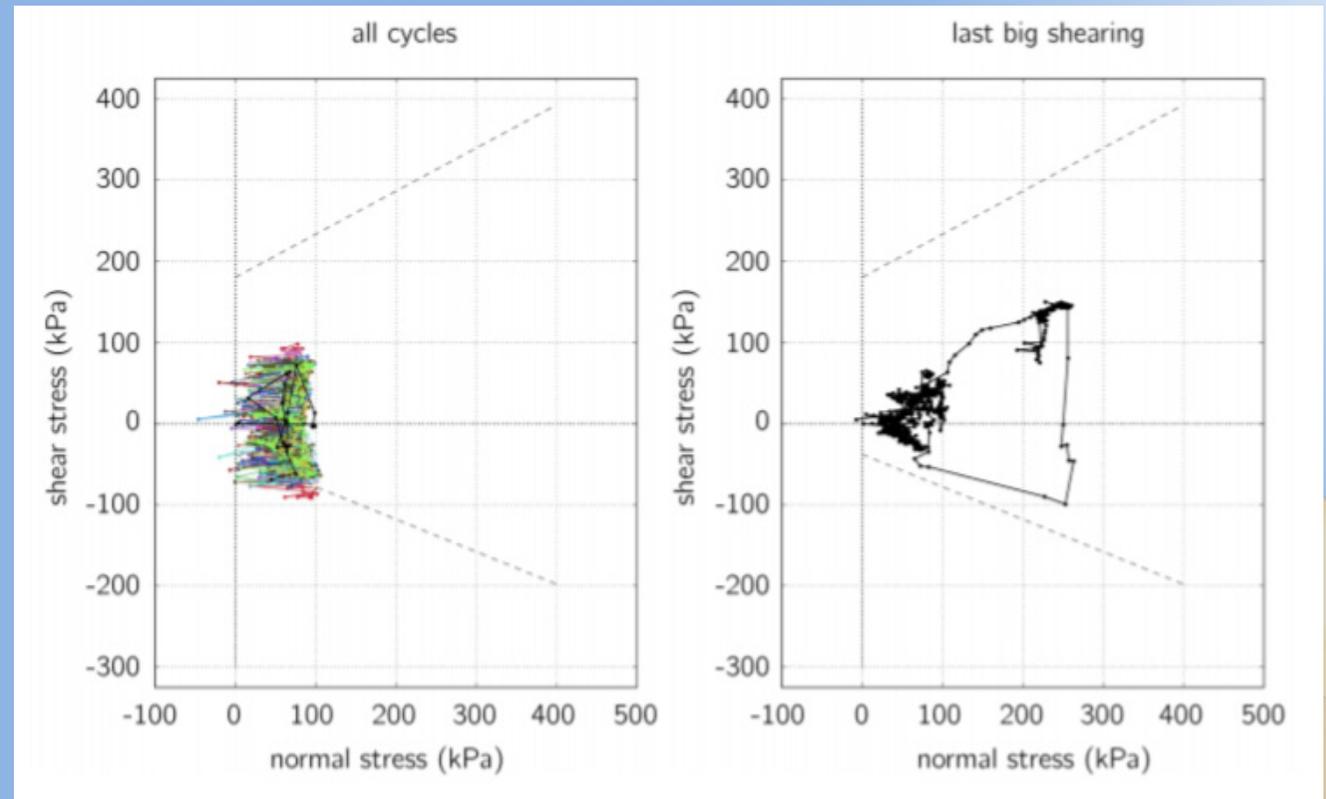
Campagne expérimentale

PHASE 2 : Essais cycliques CNS

Essai H3

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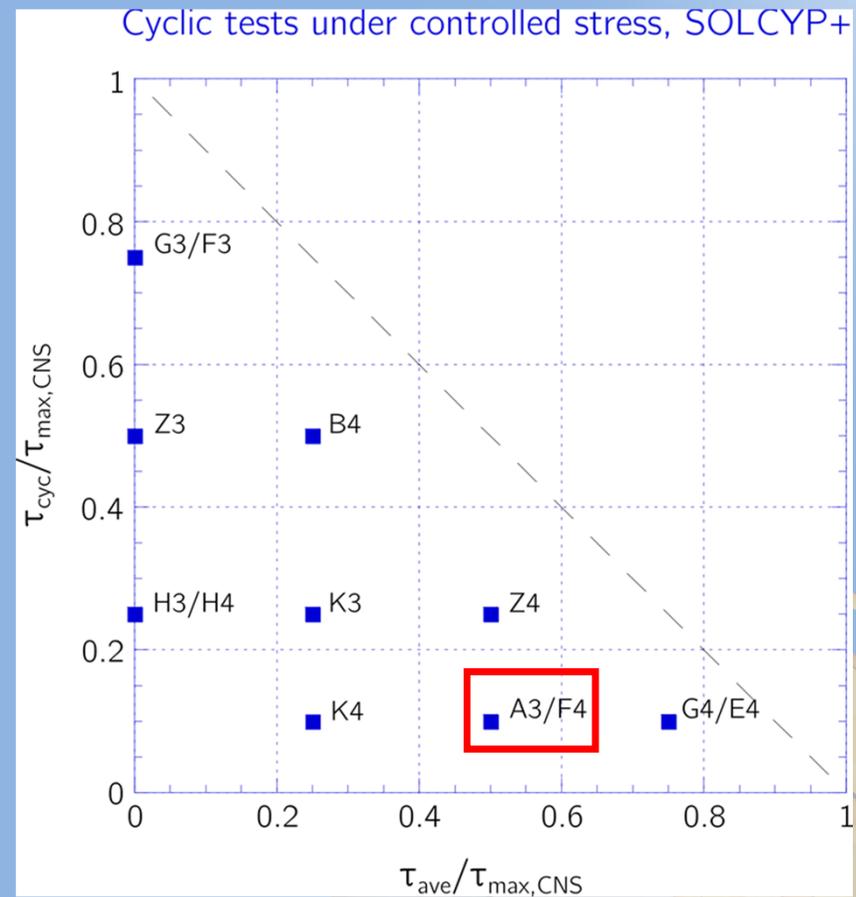
Campagne expérimentale

PHASE 2 : Essais cycliques CNS

Essais A3 / F4

$$\tau_{ave} = 155 \text{ kPa (50 \%)}$$

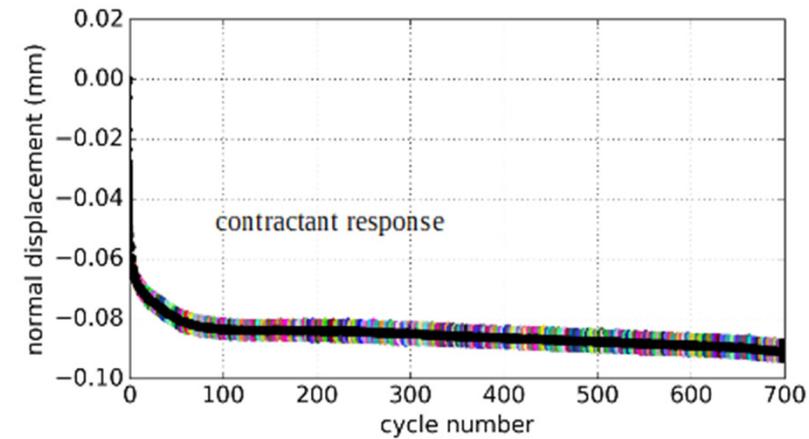
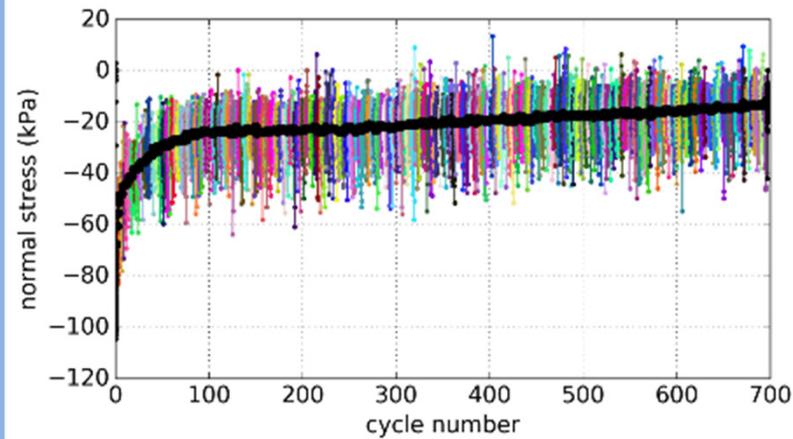
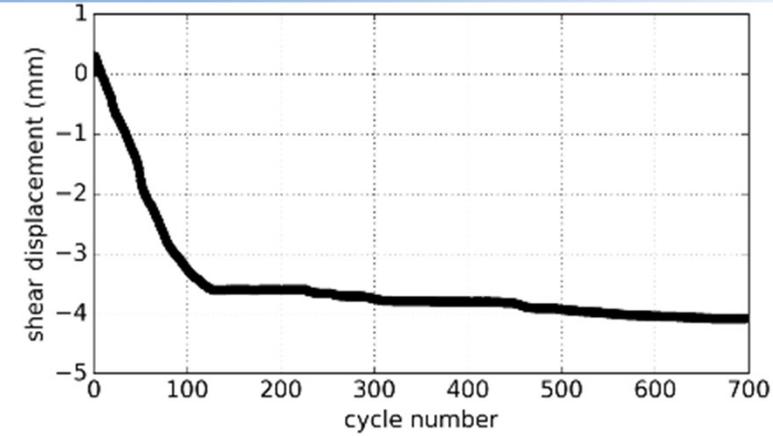
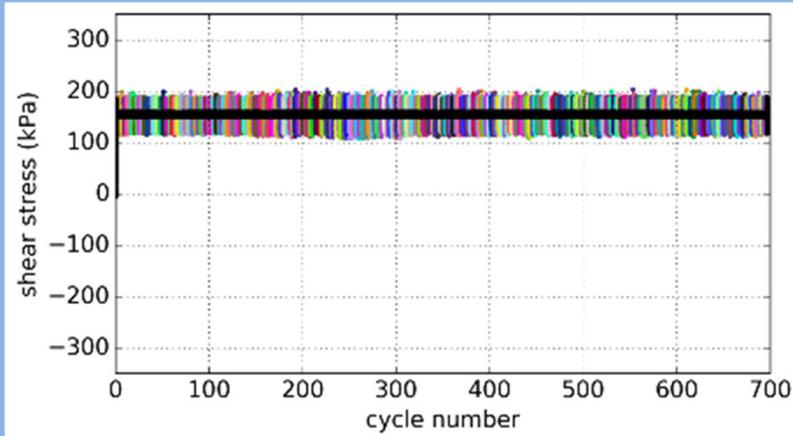
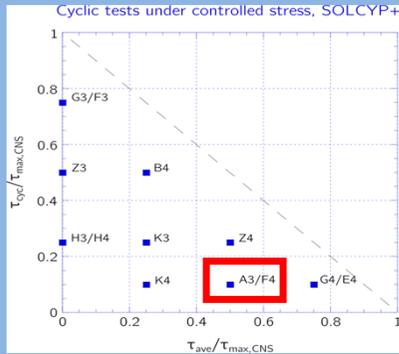
$$\tau_{cyc} = 31 \text{ kPa (10 \%)}$$



Campagne expérimentale

PHASE 2 : Essais cycliques CNS

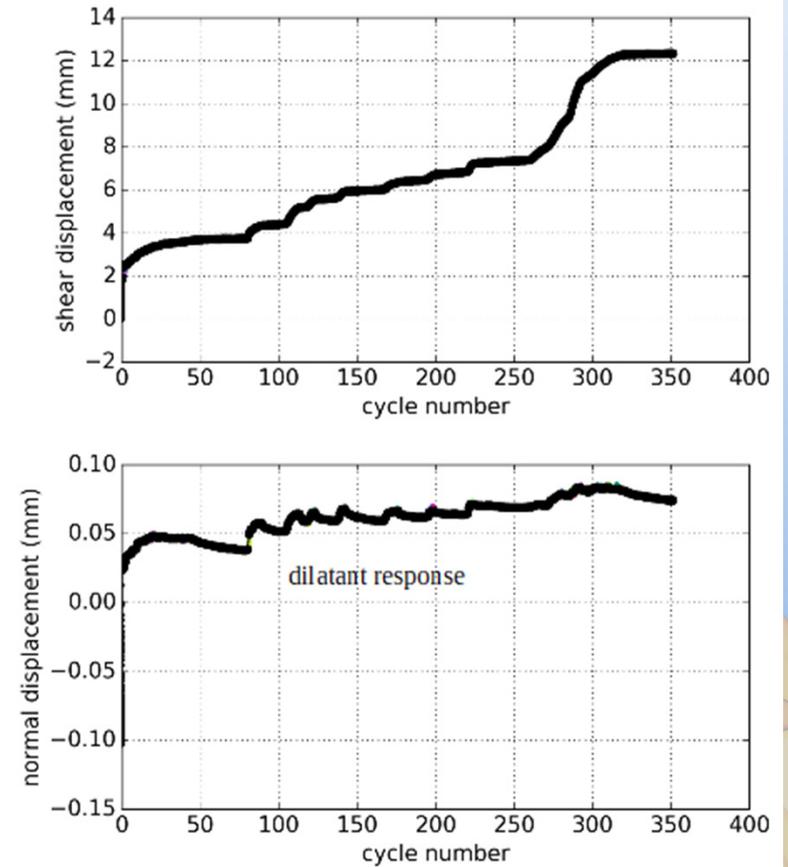
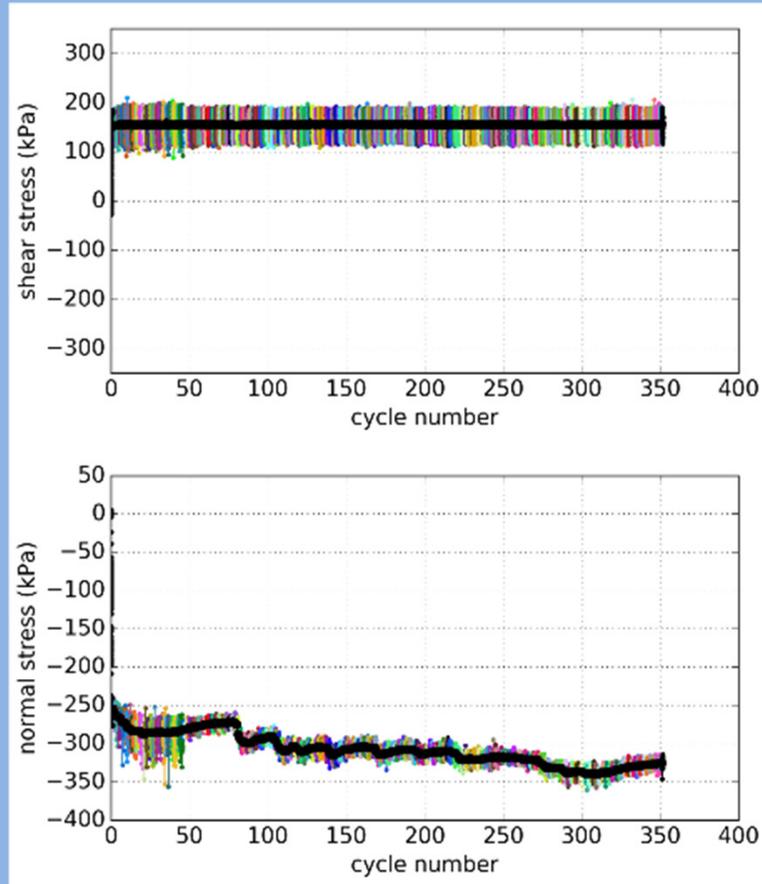
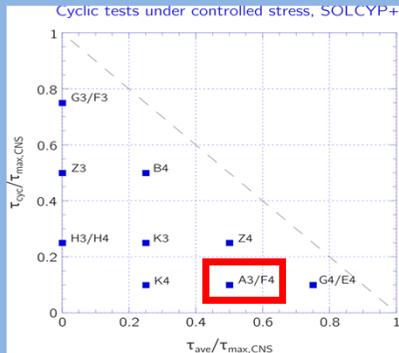
Essai A3



Campagne expérimentale

PHASE 2 : Essais cycliques CNS

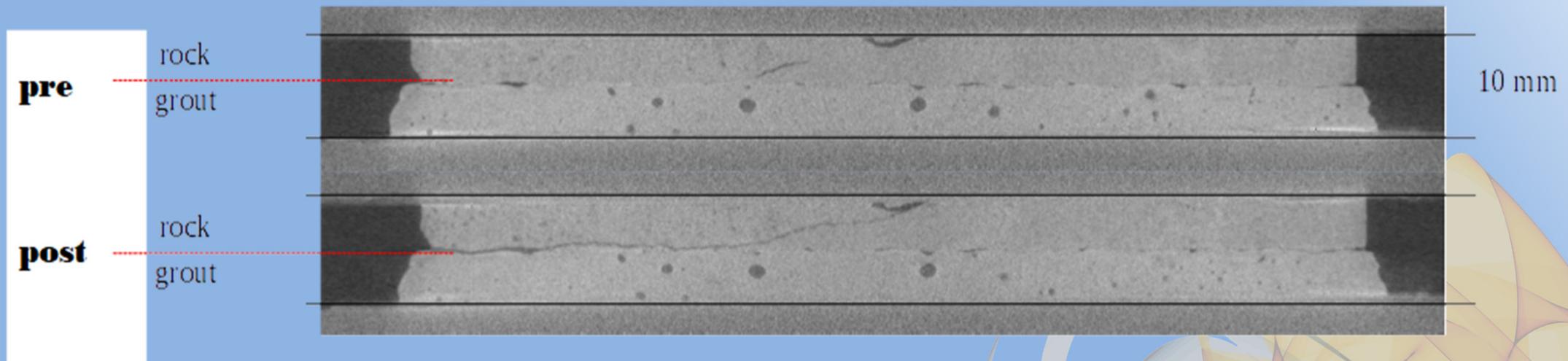
Essai F4



Campagne expérimentale

PHASE 2 : Essais cycliques CNS

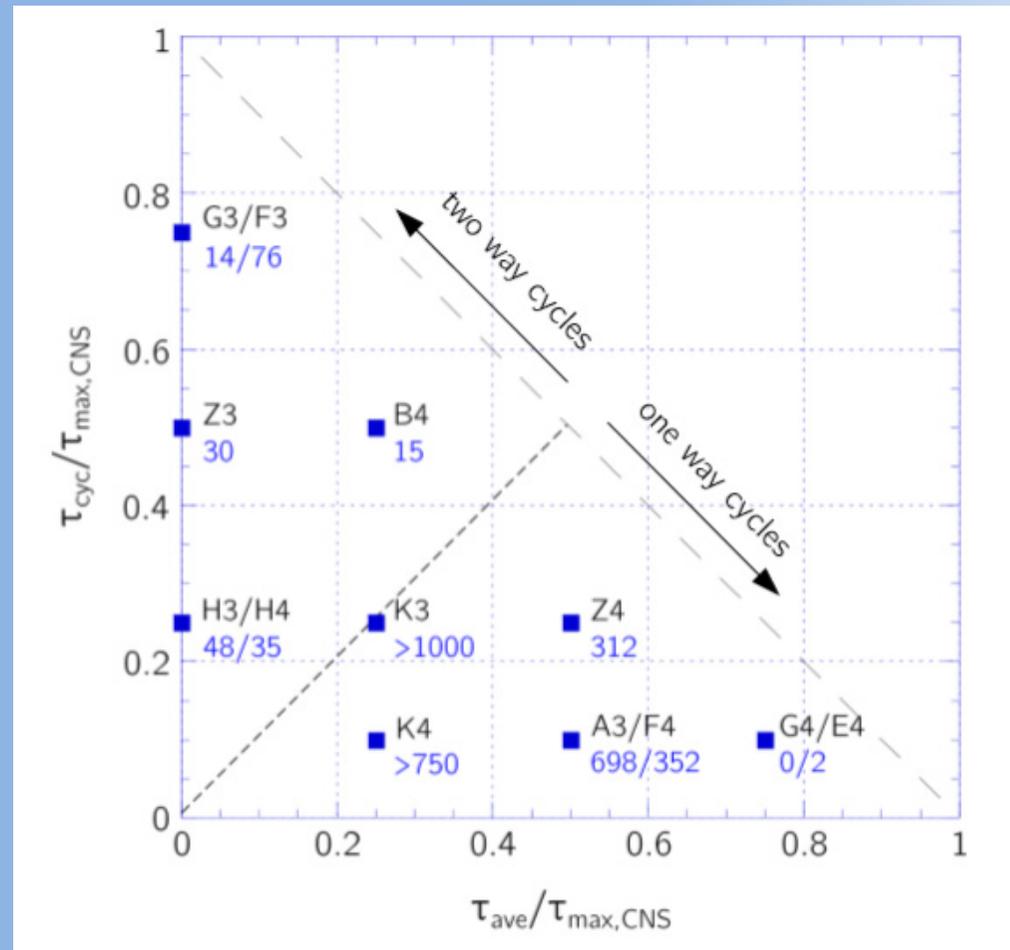
Slice 650



Campagne expérimentale

PHASE 2 : Essais cycliques CNS

Essais alternés (2-way)
plus agressifs



Conclusions et perspectives

CONCLUSIONS

- Phase expérimentale conduite en deux temps : monotone / cyclique
- Résistance au cisaillement intimement liée à l'évolution des aspérités en conditions CNS (\Leftrightarrow contraste des propriétés roche / coulis) : ici dégradation rapide des aspérités, probablement favorisée par la présence d'eau
- Chargements alternés plus agressifs

PERSPECTIVES

- Extension de la base de données expérimentale (travaux sur la craie en 2019)



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Merci de votre attention



06 Décembre 2018

Fondations d'Eoliennes Offshore

